records is, perhaps, significant. At any rate, the existence of the residual due to the apparent value of r must be considered in any such comparison as this. Only when the value of r is zero does the residual disappear. In the computation of risk, however, it is better to assume that there is no negative correlation between the date of last killing frost in Spring and first killing frost in Fall, as this gives a small margin of safety.

SIGNIFICANCE OF THE CHARTS.

The limiting dates of the season with any other chance of safety may be determined in the same manner. A consideration of the agricultural conditions and of the planting dates of grain crops leads to the belief that the risk of frost damage may reasonably be carried when the chance of killing frost falls to 1 in 10 and that crops should generally be harvested before the chance of killing frost in Fall has risen much above that ratio. If these dates are observed, the available growing season is that which may be expected to occur in about four-fifths of the years. That is—

$$P_s = 0.90$$
$$P_a = 0.90$$
$$0.90 \times 0.90 = P'$$
$$P' = 0.81 \text{ or about } 4/5.$$

The results are, of course, the same if it be assumed that a season free from killing frost in about four years in five is required for successful agriculture.

Here

$$P' = 0.80$$

but

$$P' = P^2$$

then

$$P^2 = 0.80$$
$$P = \sqrt{0.80}$$
$$P = 0.894$$
$$= 9/10 \text{ (approx.)}$$

therefore

$$P_s = 9/10$$
$$P_a = 9/10$$

The maps presented as figures 3, 4, and 5 (charts XLIV–121 to 123) are intended to supplement rather than to supersede the maps showing average conditions. The usual maps of average conditions will continue to be more accurate for the information they are able to give, viz, the dates after or before which the chance of frost is 1/2 and the length of the season available in 1/4 of the years, because many more data are available for their construction. The new charts presented with this paper attempt to furnish information about more closely calculated periods, by means of which the degree of certainty of freedom from frost may be better calculated and farm practice accordingly better adapted to the natural conditions of the region. In general it appears that the chance of killing frost falls to 10 per cent between 10 and 30 days after the average date of the last killing frost in Spring; in the Fall the corresponding difference is about the same. In general any station has a dispersion in Spring similar to that in Fall (i. e., σ_s and σ_a are nearly equal).

In the attempt to use any generalized maps of frost conditions allowance must be made for local variations. Any maps of the United States as a whole on the scales practicable for this REVIEW, can show only the general conditions over wide areas. Within these areas the more favored places will be much less subject to frosts and will have much longer available growing seasons than those indicated by the map, while the less favored spots will have later spring and earlier fall frosts with resulting shorter growing seasons. The chance of killing frost or of a frost-free season of any given length for a station may be determined, from such maps as those accompanying this paper, by applying a correction for local conditions, and this correction must be determined for each place. The necessity of this local correction is not limited to these data but applies with equal force to all maps of average dates or conditions.

CERTAIN CHARACTERISTICS OF THE WINDS AT MOUNT TAMALPAIS, CAL.

By HERBERT H. WRIGHT, Assistant Observer.

[Dated: Weather Bureau, Mount Tamalpais, Cal., July 12, 1916.]

Mount Tamalpais, Cal., while only about 2,600 feet above sealevel, rises so abruptly from the low, surrounding country that it is specially adapted for securing wind data. Topography has little or no effect on the directions or velocities recorded.

In Table 1 will be found the prevailing wind directions for the months and for the year at Mount Tamalpais, computed for the 13 years 1899 to 1911, inclusive. The persistency of the northwest wind along this coast is quite marked, as this table shows. As lower levels are reached there is a tendency for the wind to blow more from the west, specially during the summer. In winter, at sealevel, the prevailing direction for a few months is southerly.

TABLE 1.—*Prevailing wind directions at Mount Tamalpais, 1899–1911 inclusive.*

Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
SE.	NW.	NW.	NW.	NW.	NW.	NW.	NW.	NW.	NW.	NW.	NW.	NW.

The southeast winds at Mount Tamalpais during January are due to the fact that it is midwinter, the period of greatest storm frequency, and the LOWS follow each other in such rapid succession that the winds prevalent during fair weather have little influence in determining the prevailing direction at this season.

TABLE 2.—*Average hourly wind velocities at Mount Tamalpais, Cal. (2,604 feet), 1899–1911, inclusive.*

[Miles per hour for the hour ending —]

Month.	A. M.												P. M.												Mean.
	1	2	3	4	5	6	7	8	9	10	11	Noon.	1	2	3	4	5	6	7	8	9	10	11	12	
January	19.6	20.4	20.6	20.8	20.4	20.5	20.0	21.0	20.3	19.0	18.0	17.1	16.5	16.5	17.0	17.6	18.8	19.8	20.2	21.0	21.1	21.6	21.3	20.9	19.7
February	21.4	21.5	21.3	21.4	21.2	21.2	21.0	20.0	22.2	16.7	15.4	14.3	14.2	14.1	14.6	15.5	17.0	18.9	20.4	20.7	21.1	21.2	21.5	21.3	18.9
March	21.8	21.8	21.3	21.2	21.0	20.8	20.4	18.8	17.1	15.9	14.5	13.9	14.0	14.2	15.2	16.4	17.2	18.9	20.4	21.3	22.0	22.0	21.9	21.7	18.9
April	21.8	21.8	21.7	21.5	21.2	20.7	19.4	17.4	15.0	12.9	11.7	10.9	11.2	11.9	13.1	15.0	15.4	19.3	21.2	22.7	23.4	23.6	23.0	22.3	18.3
May	24.2	24.3	24.3	23.9	23.1	21.9	19.3	16.5	13.8	11.6	10.7	11.0	11.9	12.4	14.6	16.9	19.7	22.5	24.8	26.9	27.1	26.4	25.6	24.8	20.0
June	24.1	23.5	22.8	22.8	22.0	20.3	18.1	15.5	14.0	11.0	9.7	9.2	9.4	10.0	11.4	13.8	16.6	19.1	21.8	24.1	25.4	25.4	25.2	24.7	18.3
July	20.4	19.5	19.2	18.8	18.0	16.7	14.7	12.9	11.5	9.4	8.0	7.2	7.0	7.5	8.6	10.5	13.0	15.8	17.8	19.7	20.8	21.9	21.7	20.9	15.1
August	17.8	17.4	17.2	16.6	15.9	15.0	13.5	11.6	10.1	8.7	7.8	7.3	7.5	7.9	9.0	10.8	12.9	14.8	17.3	18.9	19.8	20.1	19.6	18.6	14.0
September	18.1	17.8	17.6	17.6	17.7	17.1	15.7	13.8	12.1	10.4	9.5	9.1	9.2	9.5	10.4	12.2	14.4	16.4	18.1	19.3	20.1	20.2	19.8	18.9	15.2
October	18.0	18.4	18.3	18.4	18.6	18.5	18.0	17.1	15.6	14.3	13.1	11.8	11.4	11.6	12.6	14.2	15.9	17.2	18.0	18.4	18.6	18.1	17.8	17.8	16.4
November	19.1	18.9	19.0	19.2	19.4	19.6	19.1	18.9	17.5	16.3	15.0	13.8	13.0	13.2	13.6	14.9	16.8	18.4	18.0	19.1	19.0	19.2	19.1	19.0	17.5
December	21.0	21.1	21.0	21.1	21.1	21.2	21.3	21.2	20.3	19.5	18.7	17.6	16.8	16.5	17.1	17.8	19.1	20.3	20.2	20.6	20.7	20.8	20.9	21.0	19.9
Year	20.6	20.5	20.4	20.3	20.0	19.5	18.4	17.1	15.8	13.8	12.7	11.9	11.8	12.1	13.1	14.6	16.4	18.4	19.8	21.1	21.6	21.7	21.4	21.0	17.7

TABLE 3.—*Average hourly wind velocities at San Francisco, Cal. (220 feet), 1899–1911, inclusive.*

[Miles per hour for the hour ending —]

Month.	A. M.												P. M.												Mean.
	1	2	3	4	5	6	7	8	9	10	11	Noon.	1	2	3	4	5	6	7	8	9	10	11	12	
January	6.3	6.4	6.4	6.4	6.4	6.4	6.6	6.8	6.9	7.3	7.5	7.4	7.8	8.1	8.0	8.0	7.9	7.7	7.4	7.1	6.9	6.6	6.3	6.3	7.1
February	6.1	5.8	5.7	5.7	5.6	5.6	5.8	6.0	6.4	7.0	7.2	7.4	8.1	8.8	9.3	9.5	9.6	9.3	8.9	8.2	7.4	7.1	6.7	6.2	7.2
March	7.2	6.9	6.8	6.6	6.4	6.6	6.3	6.7	7.1	7.8	8.2	8.8	10.0	11.0	12.1	12.8	12.7	12.4	11.5	10.5	8.7	8.3	7.8	7.3	8.8
April	7.3	7.0	6.7	6.3	6.1	6.0	6.0	6.5	7.2	7.7	8.4	9.8	12.0	13.3	14.3	15.2	15.3	14.8	13.8	12.5	11.1	10.0	9.1	8.1	9.8
May	8.5	7.8	7.2	6.9	6.6	6.2	6.4	6.6	7.0	7.9	9.4	11.5	14.0	15.2	16.5	17.1	17.1	16.6	15.5	14.3	12.7	11.2	10.2	9.1	10.9
June	9.3	8.9	8.3	7.7	7.5	7.1	6.9	7.3	7.8	8.7	10.5	12.2	15.8	17.5	18.8	19.4	19.7	19.2	18.1	16.4	14.9	13.0	11.5	10.1	12.4
July	9.9	9.3	8.6	8.2	7.8	7.5	7.5	7.5	7.8	8.5	10.4	13.0	15.4	17.7	19.3	20.4	20.8	20.1	18.9	17.0	15.3	13.7	12.4	10.9	12.8
August	9.3	8.7	8.1	7.8	7.4	7.2	7.1	7.2	7.5	8.2	9.8	11.9	14.6	16.6	18.3	19.3	19.6	18.7	17.5	15.7	14.0	12.6	11.3	10.0	12.0
September	7.3	6.9	6.4	6.0	5.6	5.4	5.3	5.5	5.8	6.3	7.5	9.5	11.8	13.5	15.2	16.4	16.7	16.2	14.5	12.8	11.4	10.1	8.8	7.9	9.7
October	5.8	5.4	5.3	5.2	4.9	4.7	4.9	5.2	5.6	6.0	6.1	7.0	8.9	10.2	11.4	12.1	12.6	11.9	10.4	9.0	8.0	7.1	6.6	6.2	7.5
November	5.4	5.5	5.3	5.3	5.2	5.2	5.3	5.5	5.7	6.0	6.3	6.6	7.1	7.6	8.2	8.7	8.8	8.5	7.8	7.3	6.7	6.3	6.1	5.8	6.5
December	5.5	5.6	5.6	5.6	5.7	5.7	5.7	5.9	6.3	6.5	6.6	6.8	7.1	7.0	7.0	6.9	6.7	6.5	6.1	5.9	5.8	5.8	5.6	5.6	6.1
Means	7.3	7.0	6.7	6.5	6.3	6.1	6.2	6.4	6.8	7.3	8.2	9.3	11.0	12.2	13.2	13.8	13.8	13.5	12.5	11.4	10.2	9.3	8.5	7.8	9.2

According to some authorities, wind velocities at low levels are greatest during the day, decrease toward nightfall, and approach a calm during the middle of the night. This order is exactly reversed on Mount Tamalpais. Table 2, giving the average hourly velocities, from 13 years record, 1899 to 1911, inclusive, shows a minimum velocity near noon. The corresponding maximum does not occur until about 9 p. m. This is shown in graphic form in figure 1, where the average velocities at this station are compared graphically with similar data for San Francisco.

The rapidity with which the velocity decreases toward midday at the upper station is shown in marked contrast to the rapid rise in velocity at the lower. Greater contrasts, of course, would be found in the daily records as a drop within an hour from 50 mis./hr. to 10 mis./hr. is not uncommon at this station.

The high winds experienced on Mount Tamalpais are, as a rule, quite gusty. These gusts are seldom shown on the automatic register save during exceptionally high winds because each gust is of so short duration. The Robinson anemometer in present general use in the Weather Bureau records the average rather than the extreme velocities. Extreme velocities of 140 mis./hr. have been recorded at Mount Tamalpais, however, and it is probable that could the individual gusts be measured accurately much higher velocities would be found.

Relations between wind velocity and temperature.—At lower levels there seems to be a direct relationship between the time of maximum temperature and maximum wind velocity, both occurring at or near the same time. No such relationship exists at this elevation nor does there seem to be any definite connection between the two elements in that respect. The reverse condition, however, is more nearly the case, for the maximum temperature occurs on the average at 2 p. m. which is about two hours after the minimum wind velocity. The minimum temperature, though, comes near 6 a. m., a time when wind velocities are still high. It thus appears that no

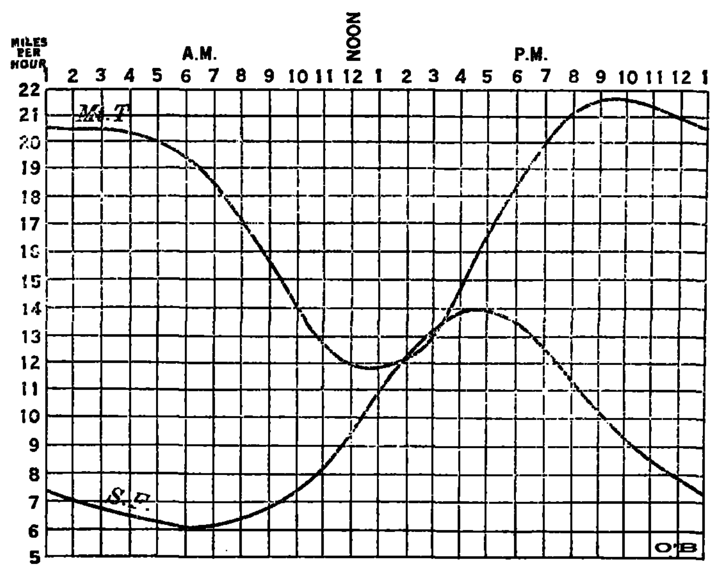

FIG. 1.—Hourly march of average wind velocities at Mount Tamalpais (2,604 feet) and at San Francisco, Cal. (220 feet). (1899-1911)

definite relationship exists at this level between temperature and wind velocity.

The decrease in velocity during the middle of the day on the mountain is doubtless due to temperature. This decrease is most marked during the warmer half-year, the season when convection is greatest. The air over the interior valleys becomes warmed under the intense insolation and expands upward, causing a slight pressure gradient which increases with elevation. The air then starts to flow down this gradient toward the ocean and the cool air over the ocean flows landward to replace the warmed air flowing off aloft (figs. 2 and 3). At night, the air over the ocean is warmer than that over the land owing to the more rapid radiation of the land surface, and the reverse action takes place, a landward breeze aloft and a seaward breeze below. This is the theory of the origin of the land and sea breeze.[1]

Mount Tamalpais probably penetrates the lower part of the transition zone between this seaward upper wind and the landward lower current. Therefore light variable winds would be expected during the time these convection-caused currents are operating.

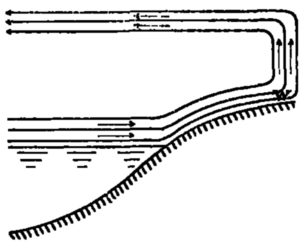

FIG. 2.—Actual circulation under seabreeze conditions (Sandström).

From observations of cloud movement, this upper seaward current is believed to blow from the northeast. Clouds are seldom recorded as moving from easterly quarters, but when they are the direction is almost always from the northeast. This freedom from clouds in this air current is probably due to adiabatic heating.

The decrease in velocity at this elevation is simultaneous with the beginning of convection in the interior valleys, i. e., about 9 a. m. It is thought, then, that the outflowing air aloft, descending as it progresss, tends to cause a change in the wind direction at this level in a clockwise direction, since during the middle of the day north and northeast winds are often recorded. This easterly wind flowing seaward at high altitudes, if it is not always strong enough to cause a change in the regular wind direction, will at least interfere and cause a decrease in velocity. In the middle of the afternoon, when convection in the interior valleys is decreasing, the wind velocity at this station begins again to increase; it reaches a maximum during the night when the air aloft is moving landward and would tend to increase velocities, and this is in exact agreement with the observed facts.

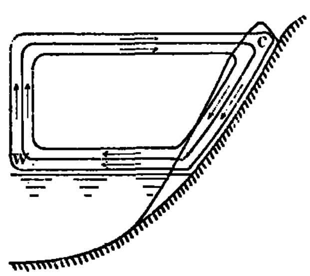

FIG. 3.—Circulation of a land-breeze (Sandström).

On rare occasions a northeast velocity of from 30 to 60 miles an hour is recorded. It is believed, however, that these high northeast winds are the result of pressure distribution rather than local convection, because they occur usually during the cooler part of the year. This belief is further strengthened by the fact that the drift of smoke over the surrounding towns and cities shows the northeast trend ofthe wind to extend down to sealevel.

Some idea of the height to which the seabreeze extends along the coast in this vicinity can be gained from observations made on Mount Tamalpais during periods when fog is prevalent over adjacent lowlands and over the ocean, a frequent condition during extended periods in summer. The estimated average height of the seabreeze in this vicinity is between 800 and 1,000 feet, assuming that it does not extend above the upper limits of the fog. This seems probable, since the main cause of fog along this coast is believed to be the mixture of air masses having different temperatures and relative humidities. There is no reason to believe that this mixture does not extend to the upper limits of the moisture-bearing wind.

Another fact that seems to strengthen the belief that the seabreeze does not extend to this level is the difference in time between the beginning of the wind at sealevel and the beginning at this elevation. In the former case the time is the middle of the forenoon, while it is retarded until the middle of the afternoon in the latter. The converse would be expected, since the surface wind encounters more friction, which would tend to retard it and cause it to lag behind the wind at somewhat higher levels.

Still another argument in favor of this hypothesis is the low relative humidity sometimes recorded at this station when the wind is northwest. For example, the case of June 13, 1916, at 5 a. m., can be cited. Fog covered the entire surrounding country below the station. The wind here was light northwest, the temperature 68.5°F., 15 to 20 degrees warmer than the air at sealevel, and the relative humidity but 5 per cent. To produce saturation, this air would have had to be cooled to 0° F. Were this wind a true seabreeze coming off the ocean, the relative humidity could not be so low, nor would the temperature be so high. It seems more likely that it was part of the upper seaward current, after it had begun to descend and start landward. Mount Tamalpais, being so near the ocean and relatively high, would not be a great distance from this turning point. This, too, would explain the anomalous, vertical temperature distribution.

1 Sandström, *in* Bull., Mt. Weather Obsy., 1912, 5: 90, fig.

RAINFALL ON DAYS WITH AIR TEMPERATURE BELOW THE FREEZING POINT.[1]

By S. TAKAYAMA.

(Abstract.)

When the air temperature near the earth's surface is below the freezing point [0°C.] precipitation generally takes the form of snow. But there are many instances of the falling of ordinary raindrops in the hours during which the mercury stands far below the freezing point. The author has picked out 36 cases in all from the meteorological registers kept at the meteorological observatories at Hakodate, Sapporo, and Nemuro for the 15 years from 1897 to 1912. In the large majority of the cases air temperature was ranging between 0° and −2°C. There were three cases in which the temperature was below −5°C. In one instance it was as low as −7.8°C.

The phenomenon under consideration occurs mostly in the early morning or at night, and is rarely observed in the daytime. Its duration is mostly less than 30 minutes, and the amount reaches scarcely a millimeter. [In Japan] this phenomenon occurs mostly with strong winds or gales from the east.

In the 36 cases referred [to] above, 8 cases were preceded by snow, 2 cases by soft hail [graupel], and 7 cases by sleet [frozen rain drops?]. In two cases it occurred with fogs. In the remaining 14 cases it was raining from beginning to end.

According to the author there are two causes of this abnormal phenomenon. In most cases it may be explained by assuming the existence of the inversion in the

1 *Reprinted from* Journal, Met'l. soc. Japan, January, 1916, 35:37-8.